*CARE-HHH-APD IR'07*
*Nov. 7-9, 2007*
*INFN - Frascati*

# LARP Long $Nb_3Sn$ Quadrupole

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OUTLINE:

- LQ goals and design
- LQ plans

# LARP 2009 Milestone

*LARP has a very challenging milestone at the end of 2009*

"Demonstrate that $Nb_3Sn$ magnets are a viable choice for an LHC IR upgrade"

Milestone set in agreement with CERN

- **Technological Quadrupoles (TQ)** for performance reproducibility

  1 m long, 90 mm aperture, $G_{nom}$ > 200 T/m, $B_{coil}$ > 12 T

- **Long Racetracks** and **quadrupoles (LQ)** addressing long magnet issues

  LQs have same features of TQs 4 m long

- **High gradient quadrupoles (HQ)** to explore performance limits

  1 m long, 90+ mm aperture, $G_{nom}$ > 250 T/m, $B_{coil}$ > 15 T

# Long Quadrupole

## Main Features:

- **Aperture:** **90 mm**
- **magnet length:** **4 m** (coil length: 3.3 m)

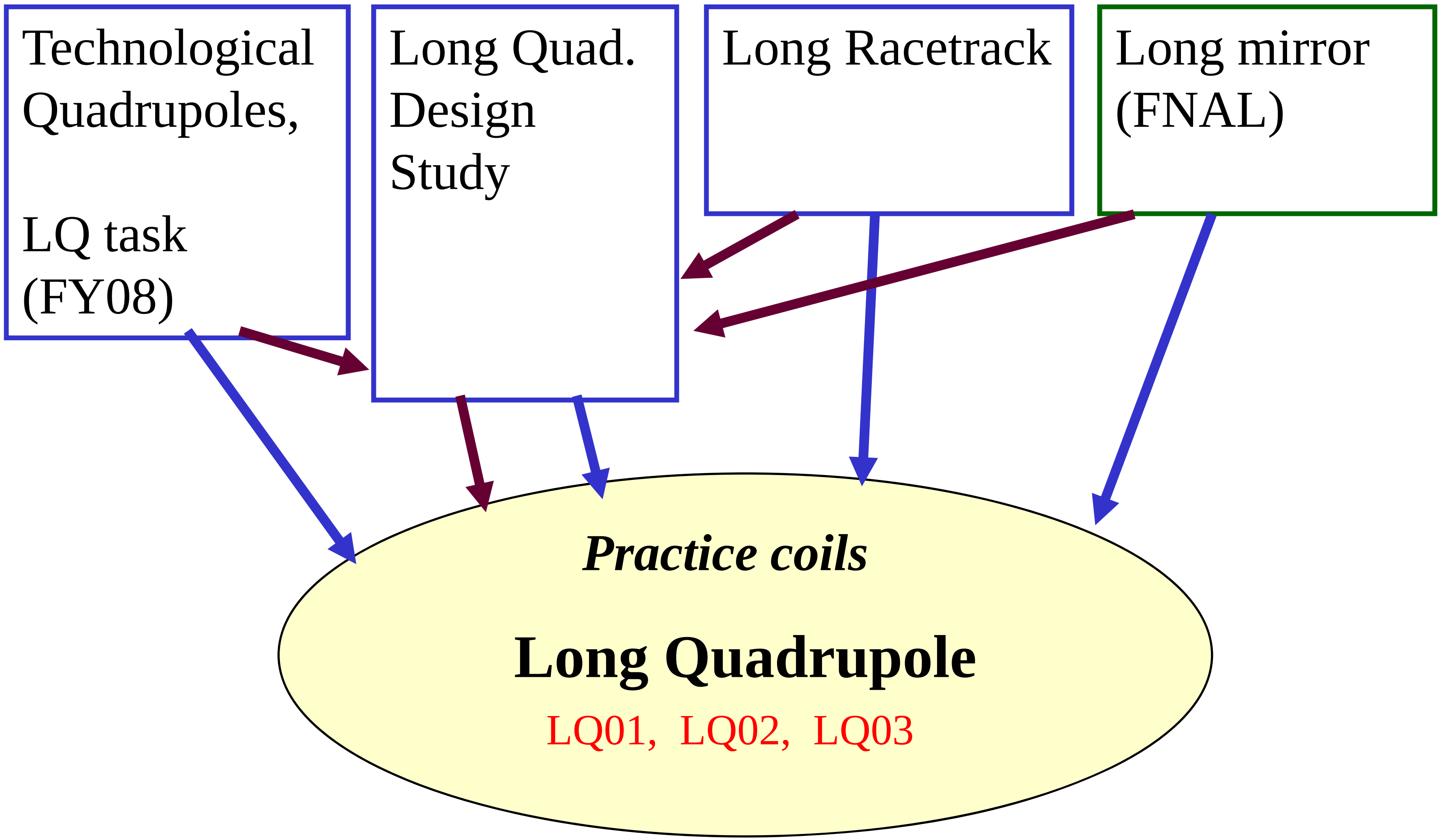
## Goal:

- **Gradient:** **200+ T/m**

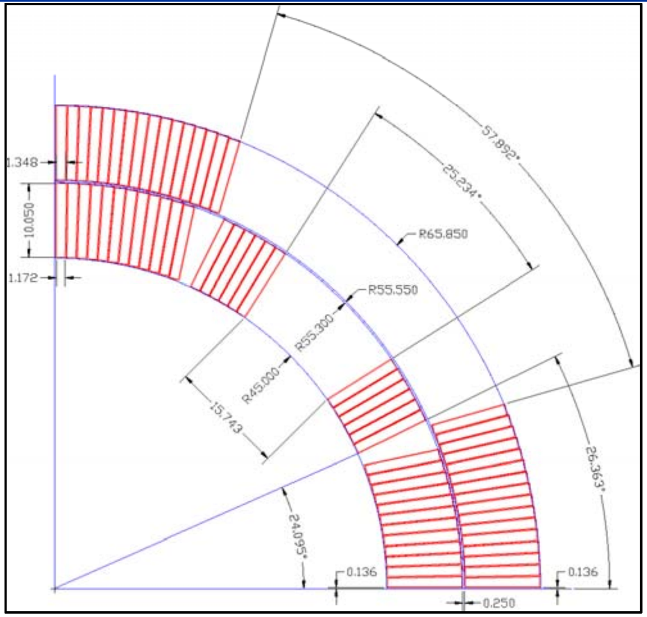
## Timeframe:

- **Performance and reproducibility by the end of 2009**
  - LQ01 by end of 2008, LQ02 and LQ03 in 2009

# The Road to the LQ



# Magnetic Design




**Coil layout = TQs**

Optimization of shell-structure cross sections in progress

| Parameter | Unit | TQC | TQS |
|---|---|---|---|
| N of layers | - | 2 | |
| N of turns | - | 136 | |
| Coil area (Cu + nonCu) | $cm^2$ | 29.33 | |
| 4.2 K temperature | | | |
| Quench gradient | T/m | **221** | **234** |
| Quench current | kA | 13.3 | 13.2 |
| Peak field in the body at quench | T | 11.5 | 12.0 |
| Peak field in the end at quench | T | 11.9 | 11.8 |
| Inductance at quench | mH/m | 4.56 | 5.03 |
| Stored energy at quench | kJ/m | 406 | 438 |
| 1.9 K temperature | | | |
| Quench gradient | T/m | **238** | **252** |
| Quench current | kA | 14.4 | 14.4 |
| Peak field in the body at quench | T | 12.4 | 12.9 |
| Peak field in the end at quench | T | 12.9 | 12.7 |
| Stored energy at quench | kJ/m | 472 | 511 |

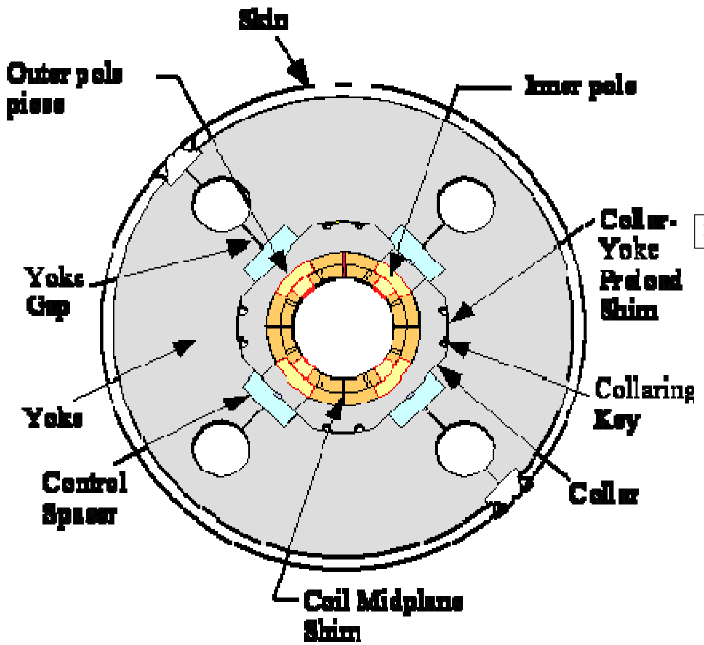
$J_c = 2400\ A/mm^2$ at 12T, 4.2K

# Conductor

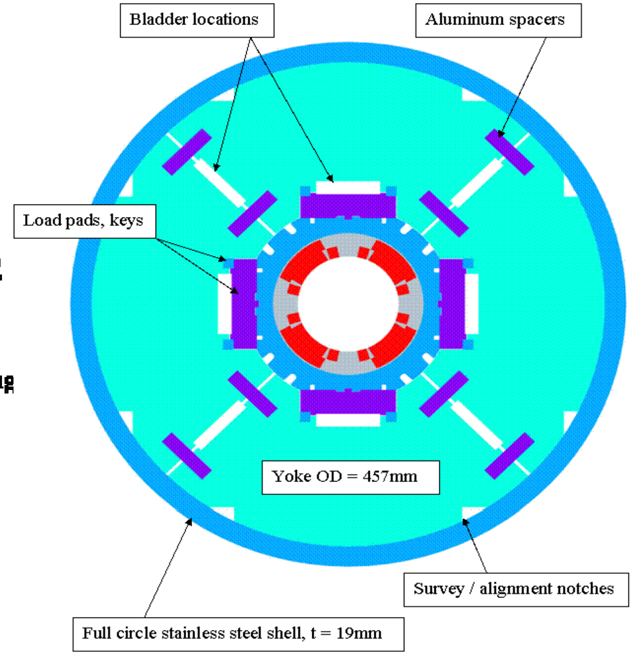
- **Cable:**
  - LQ cable design = TQ cable design
  - 27 strands, 0.7 mm diameter, 1° keystone angle
- **Strand:**
  - OST-RRP 54/61 for LQ01
    - Strand used in TQS02 coils (also in TQC02E) and LR
    - Good performance at 4.5K
    - Limited performance at 1.9K under investigation
  - Higher number of subelements considered for following LQs
    - Options: 114/127, 108/127, …

# Mechanical Design

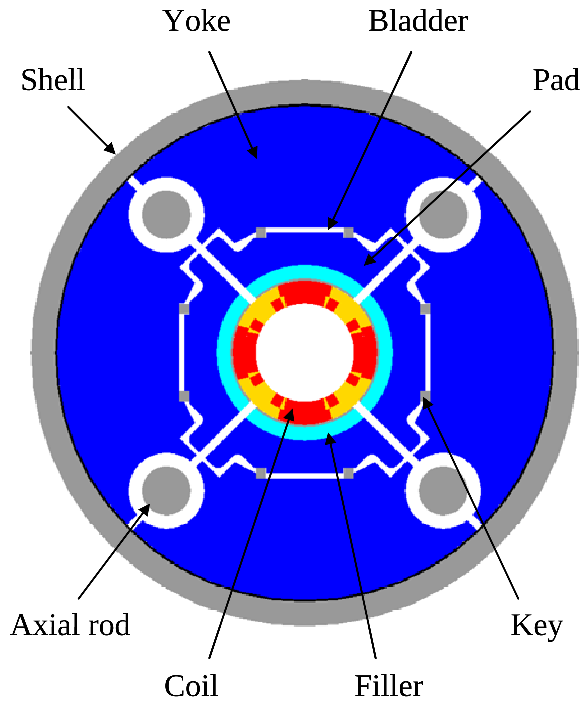
## TQC




## Hybrid design




## TQS




**Both TQ designs are options for the LQ,**

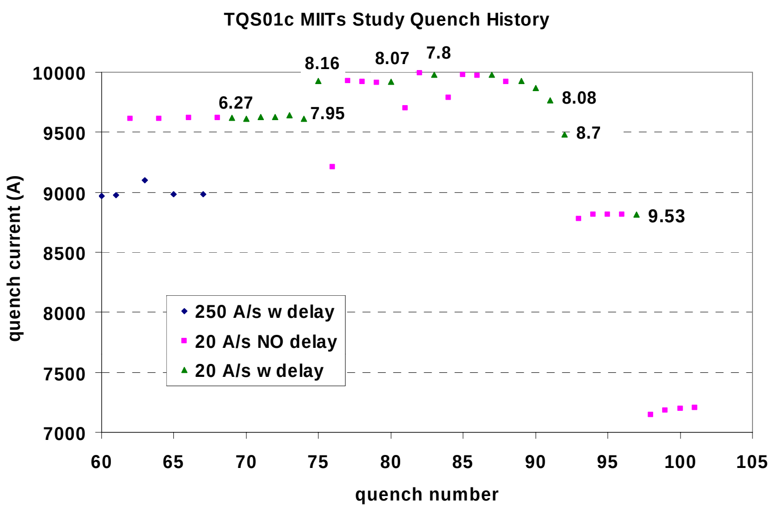
**LQ Design Review at the end of November**

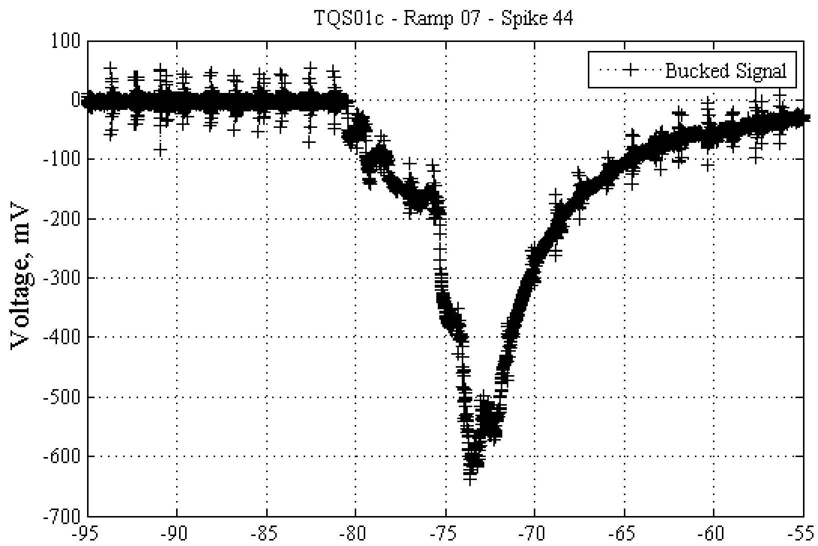
# Coil Fabrication Technology

- **LQ coils = TQ coils + minor modifications**
  - Pole material: Ti-Al-V (as TQS02 coils, also used in TQE02)
  - Ground insulation: Kapton wrap (as TQC coils)
    - 1 kV Hi-pot test
  - Soldering to traces outside of the magnet (new features)
  - Outer layer glued to the coil (as TQS coils)
  - Pins to lock inner and outer layer
    - Goal: to improve coil fabrication process reliability
  - Insulation: LQ01 will use TQ sleeve
    - Tested also on LR

# Quench Protection

- **Goal:**
  - MIITs < **7.5** ←→ Temp ~ **400 K** (adiabatic approx)
- **Quench protection parameters (4.5 K)**
  - Dump resistance: **60 mΩ** (extract ~1/3 of the energy; $V_{leads}$ ~ 800 V)
  - **100%** heater coverage (→ heaters also on the inner layer)
  - Detection time: **~5 ms** based on TQs with I > 80% ssl
  - Heater delay time: **15 ms** based on TQs with I > 80% ssl



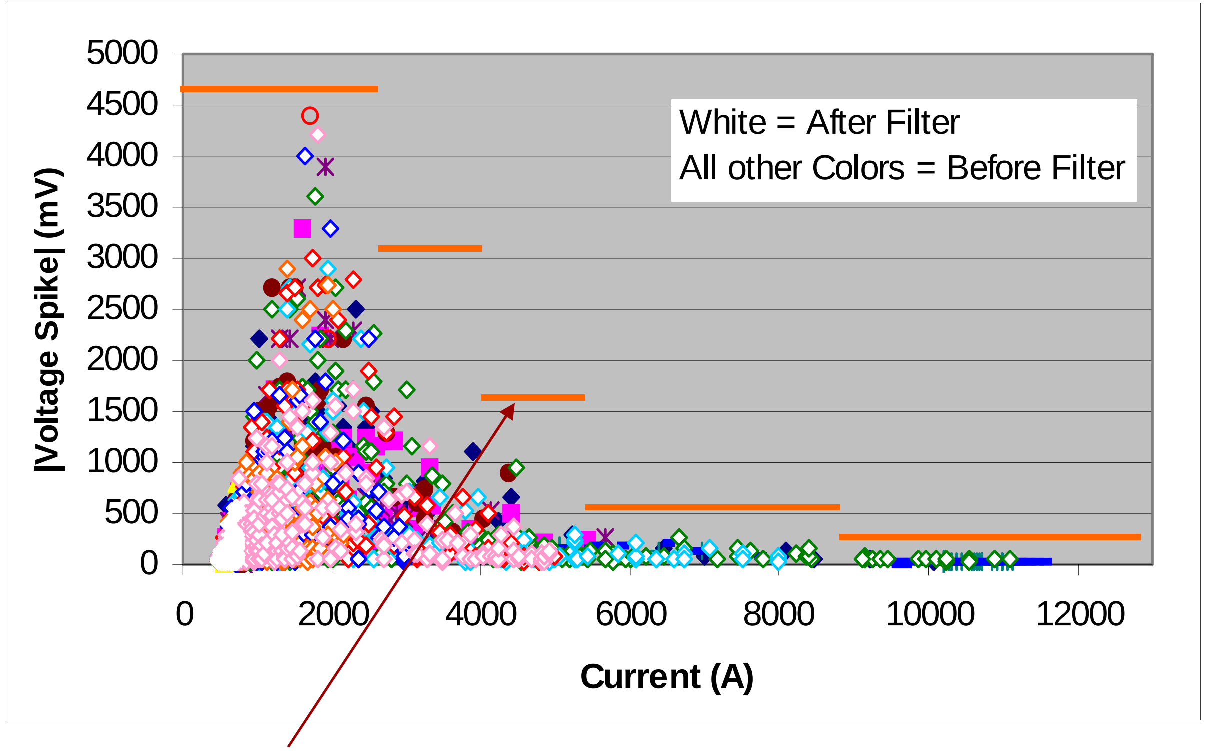



# Voltage spikes vs. current

TQS02a at 4.5K

Amplitude of voltage spikes vs. current in several current ramps.

See C. Donnelly et al., “TQS02a Voltage Spikes Analysis” FNAL TD note TD-07-015, available at: http://wwwtd.fnal.gov/info/td_library.html




- **We plan to adjust detection threshold vs. current**
  - Done for LRS01
- **Accelerator magnets need more stable conductor**
  - Better also for field quality

# Coil Instrumentation (…in progress)

**Will use Kapton "Traces" as TQs**

- **Voltage taps:** 14 Inner, 7 Outer
  - Goals : splice, pole-midplane blocks, pole turn (lead end, return end, layer-ramp, straight section), $2^{nd}$ turn
  - Goals: splice, pole turn (lead end, return end, layer-ramp)
- **Strain gauges:** 4*2 on the pole (island)
  - Plan to measure both directions at all 4 stations
- **Protection heater:** on both layers
  - Will need **two traces** (1.5 m each) **per layer**
    - May need to add stain gauges after impr. **Work in progress**
  - **Bubbles:** test at 4.5, 2.5 K and 1.9K (at the end)

# Coming soon…

- **Complete LQ Design Study Report before the LQ Support Structure Review**

**DESIGN STUDY**
**OF THE LARP LONG QUADRUPOLE**

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Will be available on line at:
https://plone4.fnal.gov/P1/USLARP/MagnetRD/longquad/designreport/

# Long Quadrupole plans

# Coil Fabrication Plans

- **I would like 8 coils available for LQ01**
  - Spare set in case of damage to 1st set during magnet assembly or operation (QP failure)
  - Spare coils available in case of LQ01 limited by some coils
- **Two coil fabrication lines (at least Rect&Imp)**
  - Avoid risk of long delays in case of equipment failure or reduced availability
  - Build larger flexibility for LARP magnet R&D
- **$5M cap FY08 plan:**
  - Wind&Cure all coils at FNAL
  - React&Impr at FNAL and BNL
  - 2 Practice Coils, 6 LQ Coils
  - Contingency: Coils 7 and 8

# Support Structure

## Each structure has unique advantages:

**Partial list of features that could benefit to the LQ plan**

- **Shell-based structure:**

  Very short magnet assembly/disassembly time

  - Attractive feature for LQ01

- **Collar-based structure:**

  Can provide accelerator magnet features: alignment, unrestricted cooldown

  - Attractive for LQ02/3

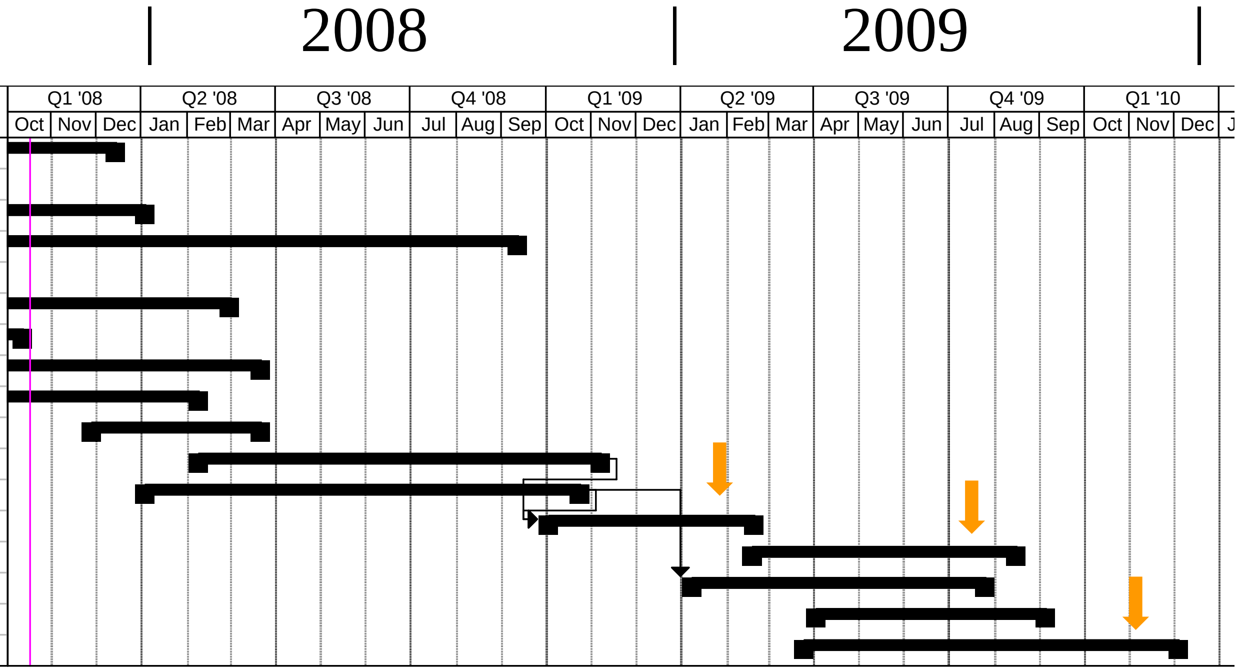
# Plan

- **LQ01 with shell-based structure**
  - Achieve LQ performance goals (~TQS02) with structure allowing quick exchange of coils if needed
- **LQ02 with collars-based structure, with LQ01 coils**
  - Demonstrate more accelerator magnet features in LQ
  - Significant savings by reusing LQ01 coils
- **LQ03 with ??? structure**
  - Demonstrate reproducibility
  - Possible performance improvement with improved conductor

**Availability of 2 structures provides risk management**

# Schedule & Budget

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | **LM** | Tue 10/17/06 | Thu 12/13/07 |
| 7 | **LRS01** | Mon 10/3/05 | Wed 8/8/07 |
| 46 | **LRS02** | Thu 8/9/07 | Wed 1/2/08 |
| 50 | **LQ Structure** | Tue 5/1/07 | Wed 9/10/08 |
| 65 | **LQ Coil Design** | Tue 11/1/05 | Thu 8/30/07 |
| 71 | **LQ Protection Heaters** | Mon 10/1/07 | Thu 2/28/08 |
| 75 | **LQ Winding/curing tooling** | Mon 2/12/07 | Thu 10/11/07 |
| 81 | **LQ Reaction/potting tooling** | Tue 4/10/07 | Thu 3/20/08 |
| 89 | **LQ Practice coil #1 (copper)** | Mon 2/12/07 | Thu 2/7/08 |
| 95 | **Practice coil #2 (Nb3Sn)** | Tue 11/27/07 | Thu 3/20/08 |
| 101 | **LQ coils set #1 (4 coils)** | Fri 2/8/08 | Thu 11/6/08 |
| 105 | **LQ coils set #2 (4 coils)** | Thu 1/3/08 | Wed 10/22/08 |
| 111 | **LQ01** | Thu 10/2/08 | Wed 2/18/09 |
| 115 | **LQ02** | Wed 2/18/09 | Fri 8/14/09 |
| 121 | **LQ coils set #3 (4 coils)** | Thu 1/8/09 | Fri 7/24/09 |
| 126 | **LQ coils set #4 (4 coils)** | Thu 4/2/09 | Fri 9/4/09 |
| 130 | **LQ03** | Wed 3/25/09 | Thu 12/3/09 |




FY08 budget (w/o contingency): $3.1M

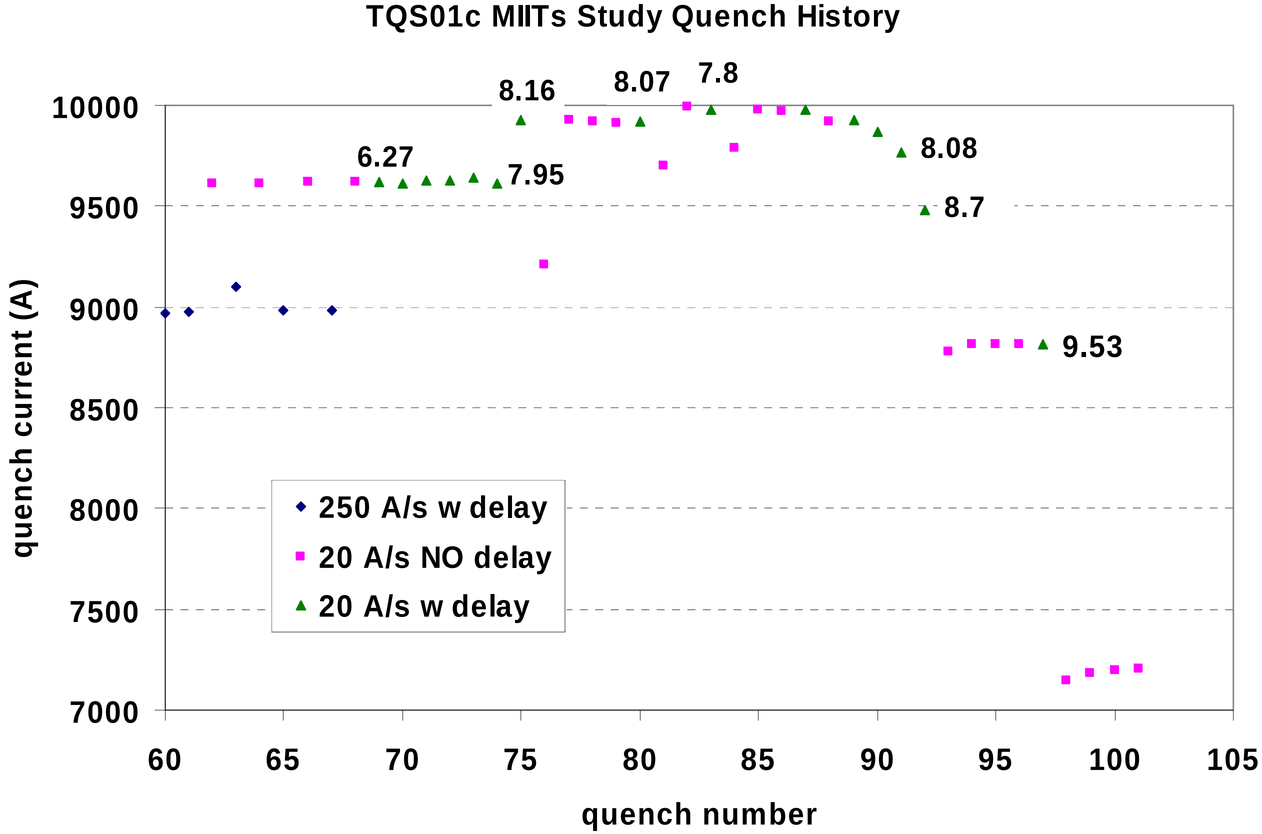
# Conclusions

- **The design of the LARP Long Quadrupole is almost complete**
  - LQ Review at BNL Nov 28-29
- **Coil fabrication has started**
  - First practice coil in progress
  - 6 (8) coils by Sept 08
- **LQ01 assembly start ~ Sept 08**
- **LQ02 and LQ03 by the end of 2009**

# Appendix

# MIITs Limit

- Impact on quench performance of high-MIITs quenches (TQS01c)
- + 4% after 8 MIITs
- - 2.9% after 8.1 MIITs
- - 7.4% after 8.7 MIITs
- - 18.4 after 9.5 MIITs
- Small bumps at 7.5 MIITs




- During TQC01 test, one QI vs. T measurement

I: 5000 A , QI: 9.05 MIITs, Peak Temp: 340 K

# FY08 Long Quad Organization

- **LQ should be a "projectized L2 task"**
  - Weekly conf-calls to check progress, and discuss problems and next steps
  - **Task sheets used as MOU between LARP and the Labs**.
  - Tasks made of sub-tasks with start/end dates, budget, and resources
  - Budget officer will generate expected spending profile (M&S and labor at each lab), and compare monthly expenses

# Plan - II

- **LQ01 plan:**
  - Structure design, fabrication, assembly with dummy coil at LBNL
  - Structure test at LN with dummy coil at BNL (possible use of FY08 contingency)
  - LQ01 assembly at BNL (FY08 cont. or FY09)
  - LQ01 test at 4.5 K at BNL
  - Shipment of LQ01 to FNAL
  - Possible test at 2.5 K at FNAL
  - Disassembly at FNAL

FY08

FY09

# Plan - III

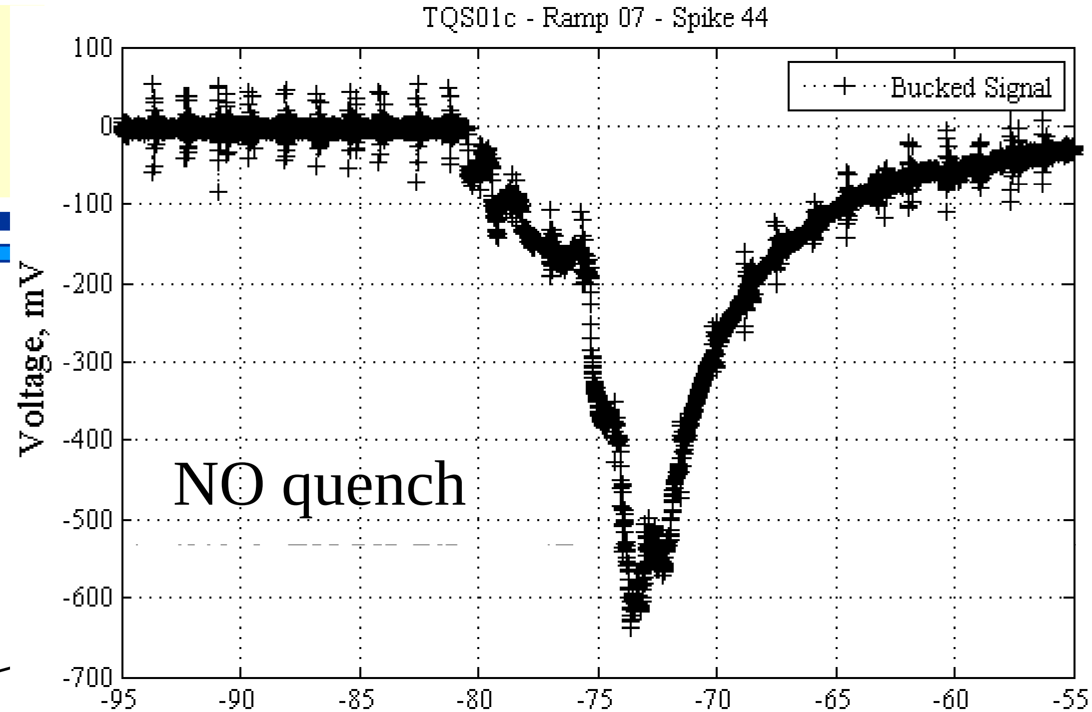
- **LQ02 plan:**
  - Long-lead items procurement at FNAL (FY08)
  - Structure procurement and QC at FNAL (FY08 contingency or FY09)
  - Assembly using LQ01 coils at FNAL
  - Test (4.5, 2.5, 1.9K) at FNAL
- **LQ03 plan:**
  - Coils fabrication will start after LQ01 test
  - Assembly and test at BNL

# Voltage spikes

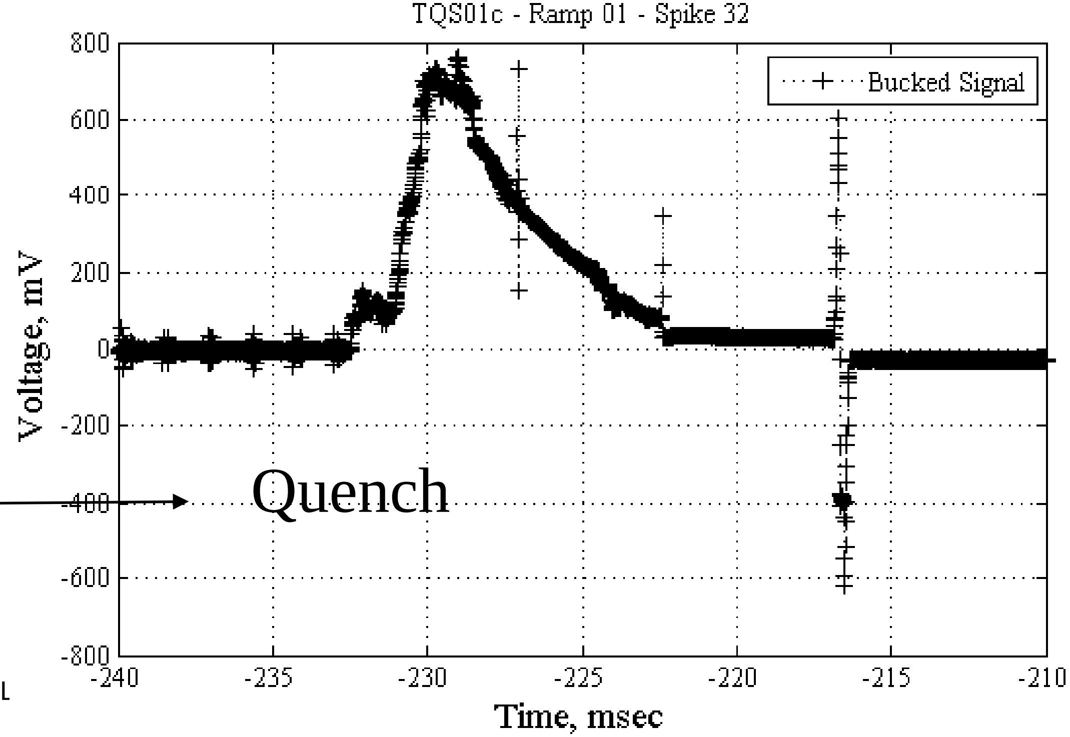
**TQS01c:**

**MJR conductor**

**RRR = 130-180**

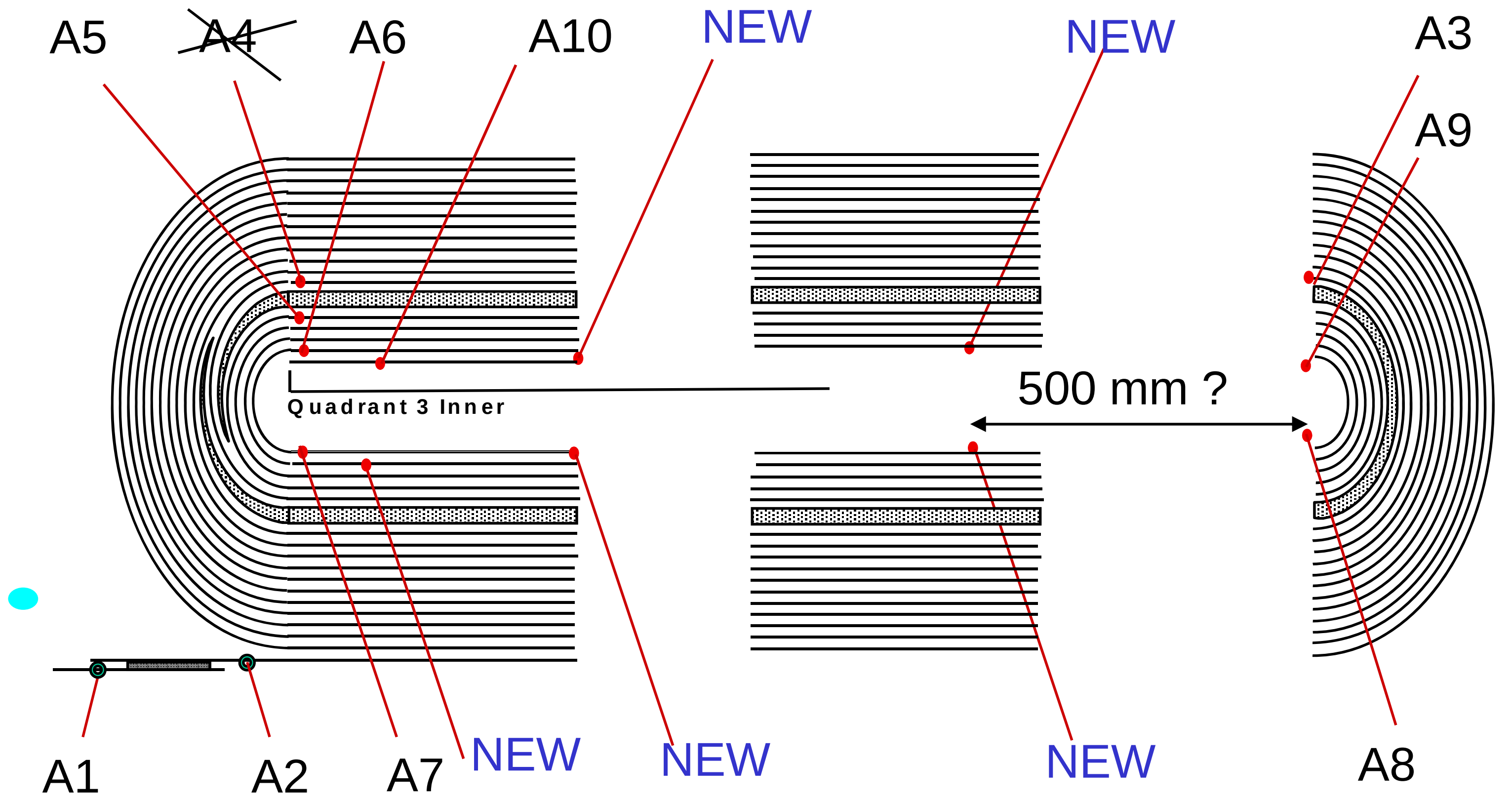



Voltage spike recorder during TQS01c test. It didn't trigger the quench protection system. Quench detection threshold was 600 mV.




Voltage spike recorder during TQS01c test. It trigger the quench protection system. Quench detection threshold was 600 mV.

# LQ inner layer




GOALS:
Splice: A1-A2; pole-midplane blocks: A3&A5 (redundancy);
lead end: A6-A7 Return end: A8-A9; layer-ramp: A10;
straight section vs. ~ends: 4 VTs NEW 2nd turn: NEW